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A REFOCUSSING SYSTEM
FOR THE PROTON LABORATORY

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Based on the results of four P-West tests that took place during 1973-74, it has been concluded that a system of focussing enclosures is necessary to eliminate halo and refocus the incident proton beam in order to produce cleaner targeting for experiments in the Proton Area. The modifications outlined in this note attempt to perform several tasks.

1. Perform an angular cut on the incident proton beam.
2. Allow better control of the beam for refocussing to smaller spots at the pre-target quadrupoles.
3. Remove muon sources to 1000 feet upstream of the target areas of the Proton Area.
4. Allow a spatial cut to be made on the beam which maps into a spatial cut at the pre-target area.
5. Perform a cleanup of off-momentum components of the beam.

The tests mentioned above were performed both before and after the installation of the proton splitting station. In both cases, the major source of noise appears to arise from observed tails of the beam with angular range .05 to .25 mrad which intercept the 3" aperture of the pre-target quadrupole after traversing a 3500 foot drift space to the Proton Area from Enclosure E. These tails which are of the order of one tenth[1] of the primary beam produce hadronic showers and fluxes of the 10^6 particles/sq. ft./10^{10} incident protons 10 feet from the beam line at the PW1 focus following the pre-target quadrupoles.

Therefore, a system must be devised which makes an angular cut on the beam to eliminate these large angle tails. Shown in Figure 1 is the general focussing enclosure layout and an envelope trace through the system. The proton beam transported through this system is derived from a fit to the actual 300 GeV proton beam and correspond to largest FWHM emittances observed to date in the proton line. ($\varepsilon_H = .50\ \pi$ mm-mr, $\varepsilon_V = .18\ \pi$ mm-mr) and contain 85% of the beam. The exact placement of the beam elements, values of the magnetic field and collimator apertures which are set to handle this beam are listed in Table I. The system will reach 500 GeV.

FUNCTIONAL DESCRIPTION

The function of each section of this system is as follows:

1. A fixed aperture beam-plug at the upstream end of the first enclosure PW-A makes an angular cut on the beam in both planes which is roughly equivalent to the cut that the pre-target quadrupoles would make in the pre-target areas. With an aperture of 2 x FWHM in both planes it is expected to absorb 8% of the beam.

2. A quadrupole doublet in the first enclosure is tuned to produce a parallel to point focus in both planes at the

collimators in the second enclosure.

3. Variable aperture primary collimators in the second enclosure. PW-B, make a spacial cut on the beam in both planes. If the apertures of these collimators are set at 2 x FWHM it is estimated that they will absorb 3% of the primary beam.

4. A backup variable aperture collimator 18 feet beyond the primary vertical collimator in PW-B, set to lie in the shadow of the PW-A and PW-B primary collimators, makes an angular cut on large angle secondaries from the primary PW-B collimators.

5. Dipoles at the end of PW-B produce a dispersion of the surviving off-momentum particles produced on the jaws of the upstream collimators.

6. Variable aperture secondary collimators at the beginning of the third enclosure PW-C, are set to lie in the shadow of the primary collimators of PW-A and PW-B and perform a crucial role in absorbing both on-momentum large angle and off-momentum secondaries from the primary collimators.

7. A quadrupole doublet in PW-C images the slit system in PW-B to the approximate location of the PW1 pit in a point to point focus in both planes. This condition[2] insures that all on-momentum and off-momentum particles scattered from the jaws of the primary collimators and surviving the slit system fit within the aperture of a 4Q120[3]. Both polarities of the PW-C doublet satisfy the criterian that all on-momentum and off-momentum particles fit within a 4" diameter circle. Therefore, there are at least two tuning conditions available

and two different beam configurations at the entrance to the pre-target area: a nearly symmetric spot 10 mm horizontal FWHM by 11 mm vertical FWHM or an asymmetric 16 mm horizontal FWHM by 11 mm vertical FWHM. Using these two beam configurations a spot size of .7 mm x .9 mm can be achieved with the symmetric spot polarity or a .4 mm x .9 mm spot size with the asymmetric spot configuration at the PW1 target station.

8. Finally, as shown in Figure 1, a number of beam plugs are inserted into the 12" pipes at the beginning and end of each enclosure. At the ends of the enclosures, the purpose of these plugs is to intercept the very low energy pions produced in the primary collimators before their decay. The beam plugs at the upstream ends of the enclosures are intended to absorb wide angle secondaries underground and thus relieve the genuine collimators which follow.

EXPECTED PERFORMANCE

Figure 2 illustrates the precise manner in which the pre-target quadrupoles are protected by the various collimators in the focussing enclosures. The beam ellipses, as was discussed earlier, contain about 85% of the proton flux. We will exhibit only the symmetric tune. Similar phase space configurations exist for the asymmetric tune. For purposes of this section we assume that the remaining 15% of the beam is spread diffusely over an area many times the size of the 85% ellipse.

We have made the approximation in these calculations that a collimator removes all particles with $X > X_o$ and $X < -X_o$ where X_o is the half aperture of the slit. The assumption is made that the angle of the particle at the collimator is irrelevant.[4] At a point later in the beam, the effect of this collimator is to have removed all particles outside of two lines on the phase space plot given by the matrix equation

$$\begin{pmatrix} x_f \\ x_f' \end{pmatrix} = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} \begin{pmatrix} \pm x_o \\ x' \end{pmatrix} \qquad -\infty < x' < \infty$$

where R is the usual beam transfer matrix from the position of the collimator to the downstream point in question.

Figure 2 illustrates quantitatively the assertions of the functional description section. The primary masking of both the vertical and horizontal phase spaces is done by the apertures of the Lambertson magnets in Enclosure H, the PW-A plug, and the PW-B collimators, The vertical backup collimator in PW-B and the collimators in PW-C lie in the shadow of the primary collimators. The cuts made by the PW-B collimators are nearly orthogonal to the cuts made by the PW-A collimators, restricting the cleanly-transmitted beam to an area not much greater than the 85% beam ellipse. This makes it possible to produce a clean beam not only at the pre-target quadrupoles but also at the other focii of the beam.

In order to reduce the background intercepting the pre-target quadrupoles,attention must be given to the behavior of the low momentum protons and pions produced from the surface interactions in the primary collimators. Therefore, vertical bending after each collimator has been incorporated into the design to sweep out low momentum secondaries. In addition, the positioning of the bending magnets and the tune of the quadrupole doublet in PW-C were varied until all off-momentum particles originating in the surfaces of the primary collimators are either intercepted by the secondary collimators or fit inside the apertures of the pre-target quadrupoles.

As an illustration of the performance of the system, Figure 3 shows a plot of θy vs dP/P for secondaries produced in the upper surface of the vertical collimator in PW-B at y = +1.2 mm. The various lines demark the regions of this space which are intercepted by the downstream collimators. Particles with positive θy are absorbed by the PW-B collimator itself. The vertical backup collimator in PW-B removes all particles with $\theta_V < -.6$ mr independent of momentum. Because of the dispersion of the 4 mr bend at the end of PW-B, the collimator aperture in PW-C has a correlation between θy and dP/P, removing particles outside of the two sloped lines (the slope is proportional to the bend angle). The unremoved secondaries lie in the trapezoid banded by $-0.6 < \theta y < 0$ mr, $-24\% < dP/P < 0\%$. This flux easily fits through the aperture of the pre-target quadrupoles (solid hyperbolae) for the symmetric spot polarity of the PW-C doublet. The secondary particles from the lower surface of the PW-B collimators and the PW-A collimator surfaces are also transmitted cleanly.

OPTIMIZATION OF THE SYSTEM

The position of the third enclosure, PW-C, was determined by the geographical constraint of avoiding existing cable ducts. This enclosure cannot be any further downstream. The distance between the first and third enclosures was somewhat arbitrary, representing a compromise between the desire for hard focussing and short cable runs and the desire to make the system work with only 30' of quadrupole in each doublet. The position of the middle enclosure was determined by the constraint that the vertical beam ellipse FWHM be no more than 20 mm in the middle of the PW-C quadrupole doublet in the asymmetric tune.

The choice of 2.125 mr bends was dictated by the restriction of 1200 amps at 500 GeV as the upper level on the current of the 240 kw Transrex power supply. The choice of the vertical plane for the bending was made because the smaller emittance in this plane allows for smaller apertures in the collimators, thus increasing the effectiveness of off-momentum collimation. The choice of polarity of the PW-A doublet, which results in a very small vertical spot and a corresponding large divergence at the PW-B collimator, was made in order to optimize the effect of the vertical backup collimator in PW-B.

ESTIMATES OF RESIDUAL BACKGROUND

It was our assumption in designing this system that the only important source of background results from elastic and inelastic scattering from the inside faces of the collimators. We estimate the probability of off-momentum 'punch through' surviving the system to be negligible. If the intensity of the beam at the collimator face is 10% of peak intensity and the average angle of surviving background is 100 μrad, then 1% of the beam scatters from our 'worst case collimator' in PW-B. While it is very difficult to calculate the fraction surviving the angle cut of the backup collimator and the momentum cut of the PW-C collimators, we roughly estimate that 10^{-7} of beam incident on the refocussing system will strike the pre-target quadrupoles. This is to be contrasted with the 5 - 10% now intercepted.

ACKNOWLEDGEMENT:

John Peoples provided many good ideas and criticisms and has taken the major responsibility in the coordination of the architectural and civil design of these enclosures.

REFERENCES:

1. Copper tag activation measurements by S. Baker indicate that 2 - 4% of the primary proton beams lie outside a 6" aperture. From the observed beam profiles it is estimated that an additional 8% of the beam lies between 3" and 4".

2. This tuning condition is optimal only if the off-momentum secondaries from the PW-B collimators are the largest source of residual background. If tertiary scattering from the backup collimators in PW-C are important a different tune of the PW-C quadrupoles is called for.

3. Only a negligible number would strike the current 3Q120, as evidenced by the phase space plots.

4. Other Monte Carlo calculations have been done in which the collimators were treated in a more realistic way with the incident particle traced through the collimator and allowed to scatter out. The results of the discussion in the text are not changed qualitatively by this refinement.

TABLE I: OPTICAL PARAMETERS USED IN DESIGN PROGRAM

Element Type	Length	Field at 300 GeV	Apertures Horiz.	Apertures Vert.	Beam FWHM at End X	Beam FWHM at End Y
Drift	914.2'					
Collimator	0.		±17.0	±11.0 mm	16.8 mm	10.6 mm
Drift	3.60					
QH331W	15.00	2.960 kG/in			15.0	12.0
Drift	5.75				13.5	13.0
QV331W	15.00	-3.157 kG/in			11.4	14.0
Drift	23.05				10.4	12.7
BV331W	10.00	6.975 kG			10.0	12.1
Drift	216.70				3.52	0.98
Col. CV341W	0.		± 4.0	± 1.2	3.52	0.98
Drift	18.5				3.61	1.43
Col. CV342W	0.		± 6.0	± 2.22	3.61	1.43
Drift	4.5				3.66	1.62
BV341W	20.00	-6.753 kG			3.98	2.60
Drift	158.5				9.42	11.3
COL. CV351W	0.0		±16.2	±13.8	9.4	11.3
Drift	15.88				10.0	12.2
BV351W	10.00	6.975 kG			10.5	12.7
Drift	1.00				10.5	12.8
QH351W	15.0	-3.072 kG/in			12.5	12.0
Drift	7.72				14.3	10.8
QV351W	15.00	+2.883 kG/in			15.9	9.7
Drift	765.40				9.8	11.5
E-95 Target					0.7	0.9

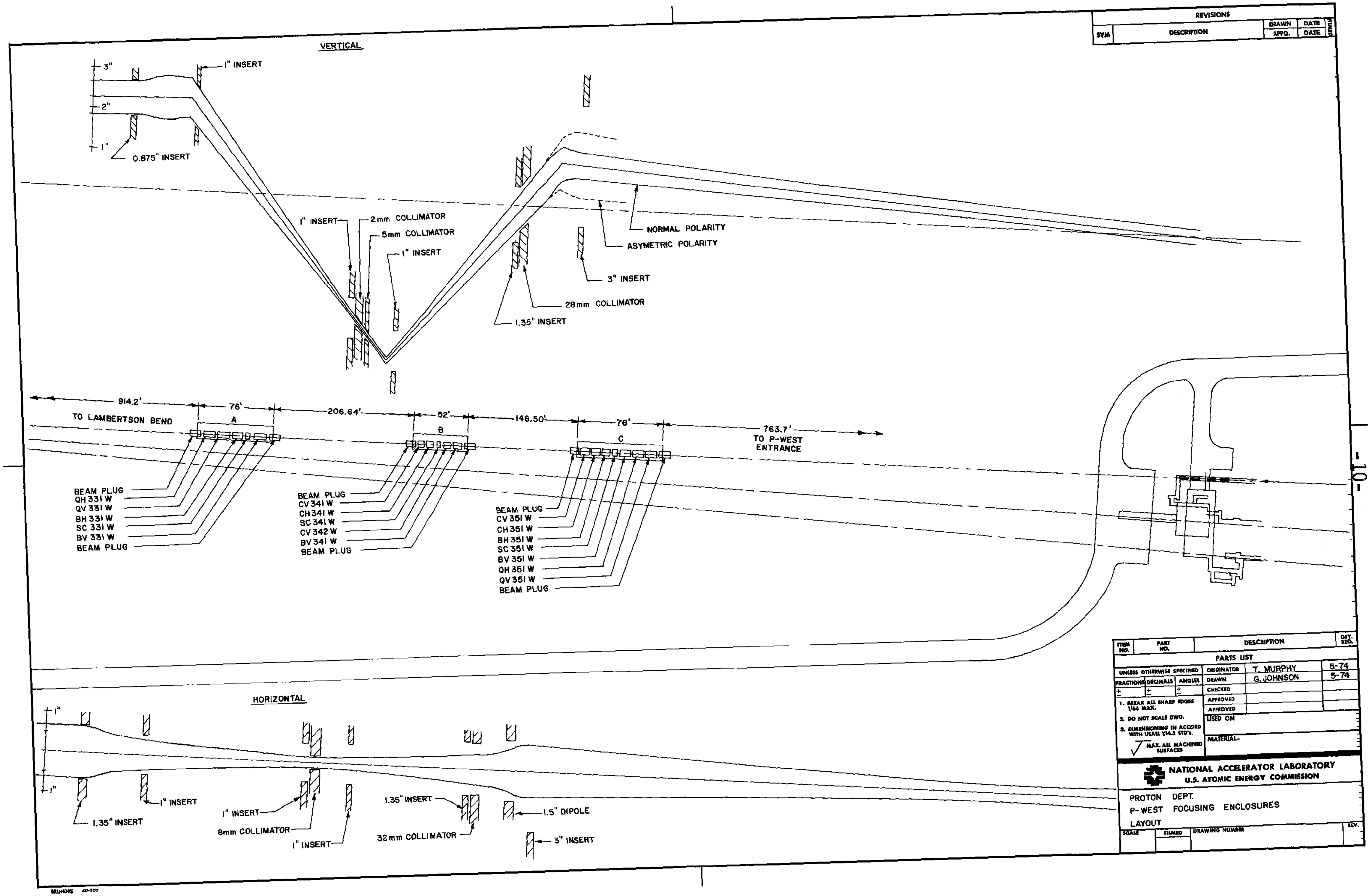
VERTICAL
3"
2"
1"
1" INSERT
0.875" INSERT
1" INSERT
2mm COLLIMATOR
5mm COLLIMATOR
1" INSERT
NORMAL POLARITY
ASYMETRIC POLARITY
3" INSERT
28mm COLLIMATOR
1.35" INSERT
914.2'
76'
206.64'
52'
146.50'
76'
763.7'
TO LAMBERTSON BEND
A
B
C
TO P-WEST ENTRANCE
BEAM PLUG
QH 331 W
QV 331 W
BH 331 W
SC 331 W
BV 331 W
BEAM PLUG
BEAM PLUG
CV 341 W
CH 341 W
SC 341 W
CV 342 W
BV 341 W
BEAM PLUG
BEAM PLUG
CV 351 W
CH 351 W
BH 351 W
SC 351 W
BV 351 W
QH 351 W
QV 351 W
BEAM PLUG
HORIZONTAL
1"
1"
1.35" INSERT
1" INSERT
1" INSERT
8mm COLLIMATOR
1" INSERT
1.35" INSERT
32mm COLLIMATOR
1.5" DIPOLE
3" INSERT
REVISIONS
SYM
DESCRIPTION
DRAWN
DATE
APPD.
DATE
ITEM NO.
PART NO.
DESCRIPTION
QTY. REQ.
PARTS LIST
UNLESS OTHERWISE SPECIFIED
FRACTIONS
DECIMALS
ANGLES
1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH USASI Y14.5 STD's.
MAX. ALL MACHINED SURFACES
ORIGINATOR
T. MURPHY
5-74
DRAWN
G. JOHNSON
5-74
CHECKED
APPROVED
APPROVED
USED ON
MATERIAL-
NATIONAL ACCELERATOR LABORATORY
U.S. ATOMIC ENERGY COMMISSION
PROTON DEPT.
P-WEST FOCUSING ENCLOSURES
LAYOUT
SCALE
FILMED
DRAWING NUMBER
REV.
BRUNING 40-107

Figure 1

Phase Space Masking by Collimators and Beam Ellipses at Entrance to Proton West

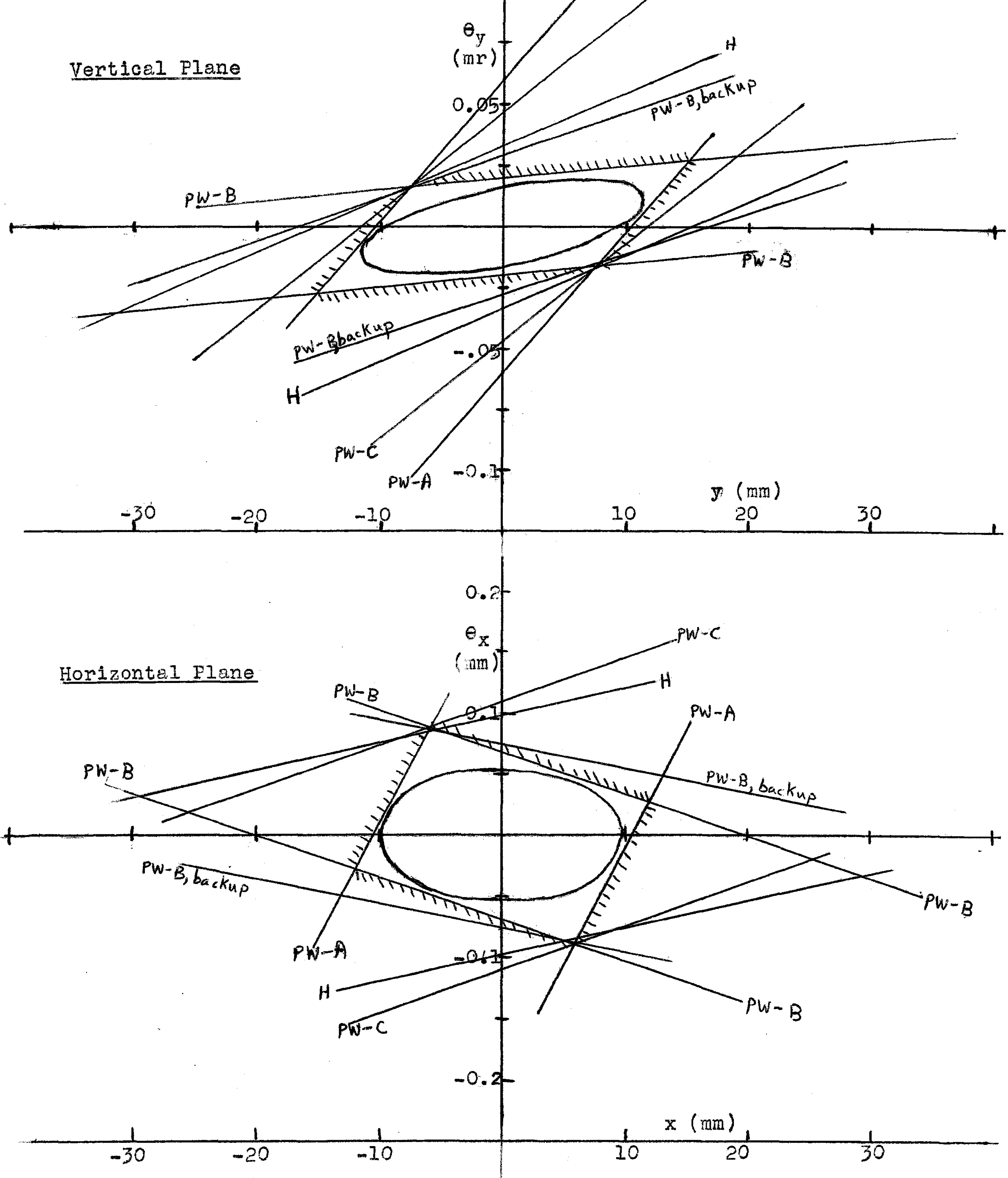

Fig. 2

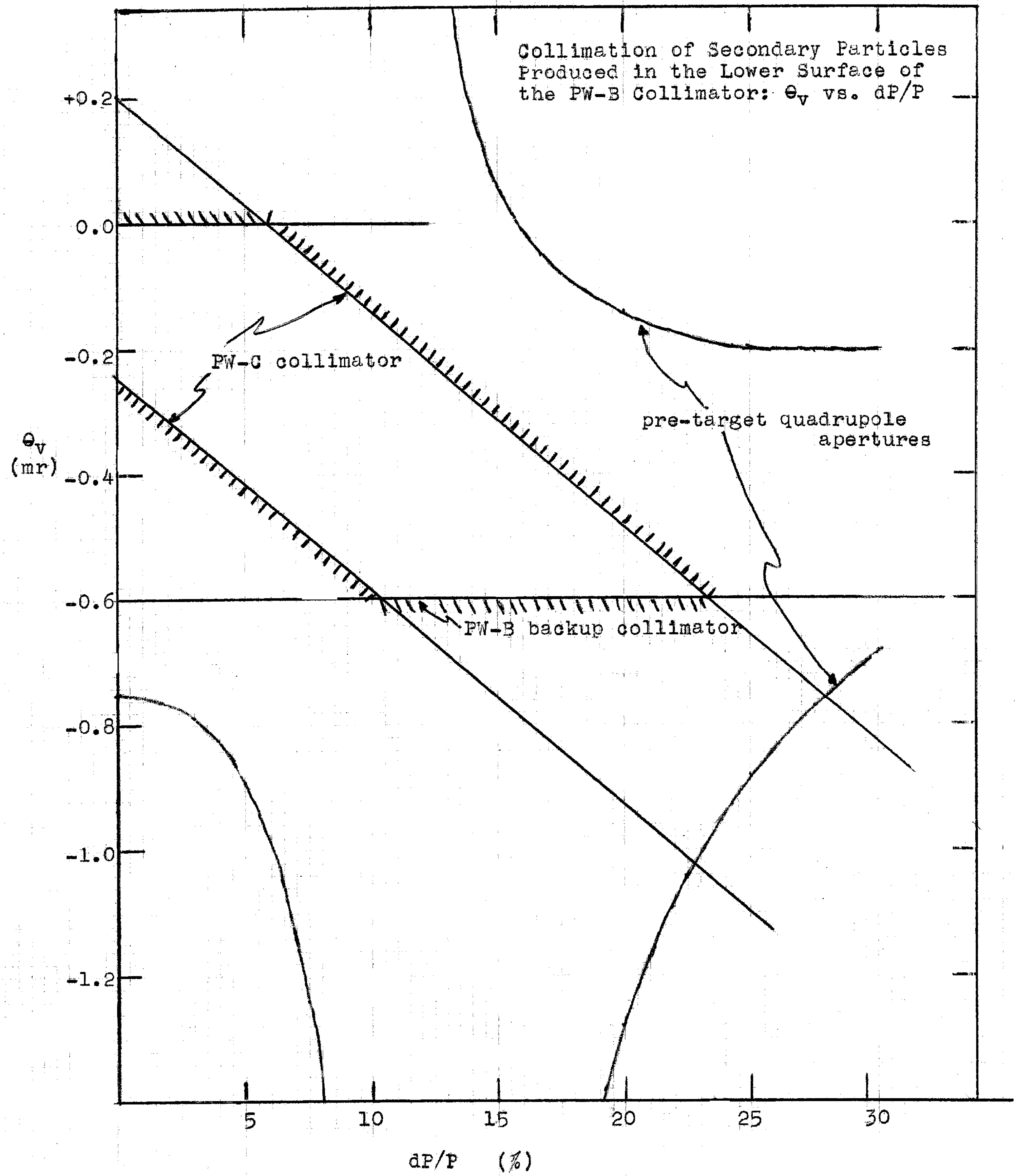
Collimation of Secondary Particles
Produced in the Lower Surface of
the PW-B Collimator: Θ_v vs. dP/P
+0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
Θ_v
(mr)
PW-C collimator
PW-B backup collimator
pre-target quadrupole
apertures
5
10
15
20
25
30
dP/P (%)

Fig. 3